REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
March 96

3. REPORT TYPE AND DATES COVERED
Final Report 01May92 - 30Apr95

4. TITLE AND SUBTITLE
Instrumentation for and indices of marine mammal responses to low frequency sound

5. FUNDING NUMBERS
G
N00014-92-J-1680
R&T Code: 4414214

6. AUTHOR(S)
Jones, David R.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Dept. of Zoology, Univ. of British Columbia
6270 University Blvd.
Vancouver, B.C. V6T 1Z4 Canada

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
800 N. Quincy St.
Arlington, VA 22217-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

19960404 021

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Our objective was to develop instrumentation capable of remotely monitoring behavioral and physiological variables from marine mammals. A stomach temperature telemeter (STT) which transmits to a receiver in the animal mounted data logger was developed for recording prey ingestion events. Feeding studies demonstrated that with proper calibration, the STT system can indicate the timing of prey ingestion and can also be used to estimate the quantity of prey ingestion. A heart beat detector/telemeter and receiving module was developed and found to be suitable for recording heart rate from northern elephant seals, California and Steller sea lions, and harbor porpoise. We developed and successfully tested at sea a device for the remote release and retrieval of data loggers. Our custom data loggers and sensors have been successfully applied to a study of the at-sea behavior and physiology of northern elephant seals. During migration, the patterns of dive depth, swim speed, and heart rate are fairly predictable. Therefore, these variables should be good indices of disturbance responses. In the lab, the heart rate response to various threat stimuli is one of dramatic bradycardia, which should be a good response index.

14. SUBJECT TERMS
Marine mammals, Instrumentation, Dive Behavior, Monitoring

15. NUMBER OF PAGES
3 + SF298

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

53-85

FINAL TECHNICAL REPORT
ONR Grant#: N00014-92-J-1680 R&T Code: 4414214

GRANT TITLE: Instrumentation for and indices of marine mammal responses to low frequency sound

PI: Dr. David R. Jones

INSTITUTION: University of British Columbia, Dept. of Zoology
Vancouver, B.C. V6T 1Z4 Canada

AWARD PERIOD: 1 May 1992 - 30 April 1995

DATE OF REPORT: 8 March 1996

STATEMENT OF THE PROBLEM:

The recent introduction of low frequency sound (LFS) as a tool in the study of global warming has resulted in the need to determine whether LFS has any effect on marine mammals. Unfortunately, very little is known about the auditory receptive abilities of most marine mammals. Appropriate methods for collecting such data, however, are difficult to perform even in a captive situation, and many tests of LFS reception will need to be conducted in the field. Therefore, other indices of reception, or startle, must be identified. Such indices might include dive behavior, swimming velocity, foraging behavior, and certain physiological variables. Unfortunately, at the start of this award commercially available devices suitable for use on free-ranging marine mammals could only measure geolocation and dive depth.

OBJECTIVES: 1) To develop instrumentation capable of remotely monitoring behavioral and physiological variables from marine mammals. 2) To determine which variables are the most useful indicators of a behavioral or physiological response to LFS emission.

MOST IMPORTANT RESULTS:

Sensors for the following variables were investigated: swim velocity, orientation, foraging behavior, heart rate, and respiration. Three types of swim velocity transducers were examined: a turbine, a permanent magnet electromagnetic flow probe, and a differential pressure/pitot type device. The turbine is quite satisfactory for environments with limited fouling and for speeds above 0.25 ms^{-1}. The electromagnetic flow probe was found to be unacceptable due to high baseline drift and fouling potential. The differential pressure sensor is ideal for small animals with low swim speeds, but is limited by its depth rating and a small range of speeds transduced at high resolution. We tested two commercially available gimbaled electronic compasses as sensors for the transduction of 3-D orientation. However, both were considered inappropriate for most users because of high cost, limited tilt range (max $\pm 60^{o}$), and large size. A stomach temperature telemeter (STT) which transmits to a receiver in the animal mounted data logger was developed for recording prey ingestion events. Laboratory feeding studies with California and Steller sea lions demonstrated that with proper calibration, the STT system can indicate the timing of prey ingestion and can also be used to estimate the quantity of prey ingestion. This innovation was shared with a commercial vendor and should soon be available to other marine mammal researchers. A heart beat detector/telemeter and receiving module was incorporated into our data logger and found to be suitable for recording heart rate from northern elephant seals, California and Steller sea lions, and harbor porpoise. This innovation was also shared with a commercial vendor and has since been successfully applied to

southern elephant seals and bottlenose dolphins. Tests of this heart beat detector were unsuccessful with the beluga whale because of that animal's very low amplitude surface potentials, a phenomena that is probably found in other large cetaceans as well. Therefore, a custom miniature EKG amplifier was developed and added to the data logger, which allowed continuous recording of the EKG waveform. However, this approach consumes a large amount of the data logger's limited memory. Therefore, in collaboration with J. Goodyear, we successfully modified a digital medical Holter monitor to make remote, continuous high-frequency EKG recordings of the beluga whale, both in an aquarium and in the wild. These recordings have allowed us to attempt to modify the algorithm used by the Holter monitor for identification of individual human heart beats, an approach that is still underway. Two methods of measuring respiratory rate were found to be satisfactory for free-ranging animals that don't tolerate sensors placed near their nares. One method involves additional circuitry in the data logger to create an impedance pneumograph with an EKG filter so that respiration and cardiac activity can be recorded simultaneously from a single set of electrodes. The other method is a novel approach that only requires logging the timing of each heart beat with our standard data logger. We have demonstrated that respiratory rate can be found by applying power spectral analysis to elephant seal heart rate data because the peak power coincides with the breathing frequency. We have successfully deployed small data loggers that simultaneously measure dive depth, water temperature, swim velocity, prey ingestion, heart rate and respiration using the above techniques on both elephant seals and Steller sea lions and similar data loggers which record everything but prey ingestion on beluga whales. The difficulty in retrieving our archival units from Steller sea lions and belugas led us to one more development, one that was also highly recommended in the summary of the 1992 ONR sponsored "Workshop on Tagging and Tracking Technology." This innovation was a device that was successfully tested at sea for the remote release and retrieval of our data loggers. The release device consists of a VHF telemeter, an animal-based receiver/decoder, and a thermal release unit which severs monofilament attachment lines. Instrument packages were released and recovered at sea by making them positively buoyant with their VHF and ARGOS satellite antennas pointing skyward.

Our custom data loggers and sensors have been successfully applied to a study of the at-sea behavior and physiology of northern elephant seals, a species potentially vulnerable to the effects of low frequency sound emission. We used the translocation paradigm (seals are transported from the rookery to sea and released for monitoring on their return to the beach) to characterize the behavior, physiology, and energetics of the migrations of juveniles. During migration, the patterns of dive depth, swim speed, and heart rate are fairly predictable. Therefore, these variables should be good indices of disturbance responses. In the lab, we have demonstrated that the heart rate response to various threat stimuli is one of dramatic bradycardia, which should be a good response index. Our preliminary study of the foraging behavior of the Steller sea lion has demonstrated that there can be a great deal of temporal and spatial variability in foraging behavior even in a single species at one location. Therefore, until foraging behavior is more well described and its variability better understood, it will not make a good index of disturbance.

PUBLICATIONS AND ABSTRACTS:

Andrews, R.D., J.D. Williams, and D.R. Jones. 1992. Heart rate responses to apnea on land and at sea in northern elephant seals (Mirounga angustirostris). Amer. Zool. 32(5): 31A.

Andrews, R.D., D.R. Jones, J.D. Williams, D.E. Crocker, D.P. Costa, and B.J. Le Boeuf. 1993. Metabolic and cardiovascular adjustments to diving in the northern elephant seal. In: Abstracts of the tenth biennial conference on the biology of marine mammals, p.22.

Goodyear, J.D., and R. D. Andrews. 1993. The first whale ecg with a self-contained tag, and radio and satellite-linked depth and heart-monitoring tags for whales. In: Abstracts of the tenth biennial conference on the biology of marine mammals, p. 54.

Webb, P.M., R.D. Andrews, B.J. Le Boeuf, and D.P. Costa. 1993. Heart rate and oxygen consumption in elephant seals diving in the laboratory. In: Abstracts of the tenth biennial conference on the biology of marine mammals, p. 111.

Andrews, R.D., D.R. Jones, J.D. Williams, D.E. Crocker, D.P. Costa, and B.J. Le Boeuf. 1994. Thermoregulation and metabolism in freely diving northern elephant seals. FASEB Journal 8(4):9

Andrews, R.D. and D.G. Calkins. 1995. Determining the precise timing and location of foraging by Steller sea lions. In: Abstracts of the eleventh biennial conference on the biology of marine mammals, p. 4.

MANUSCRIPTS SUBMITTED OR IN PREPARATION:

Andrews, R.D., D.R. Jones, J.D. Williams, P.H. Thorson, D.P. Costa, and B.J. Le Boeuf. Heart rate responses to apnea on land and at sea in northern elephant seals. Submitted to J. Exp. Biol., Mar. 1996.

Webb, P.M., R.D. Andrews, B.J. Le Boeuf, and D.P. Costa. Heart rate and oxygen consumption of northern elephant seals during diving. Submitted to Physiol. Zool., Feb. 1996.

Andrews, R.D. and D.R. Jones. Miniature recorders for the remote monitoring of behavioral and physiological variables (in prep.).

Andrews, R.D. and D.G. Calkins. Determining the precise timing and location of foraging by Steller sea lions (in prep.).

Andrews, R.D., D.R. Jones, Y. Yeh, D.P. Costa, and B.J. Le Boeuf. The use of spectral analysis to determine respiratory frequency in elephant seals (in prep.)

Andrews, R.D., D.R. Jones, J.D. Williams, D.E. Crocker, D.P. Costa, and B.J. Le Boeuf. Cardiovascular and thermoregulatory adjustments to diving result in a low field metabolic rate (in prep.).

SCIENTIFIC PERSONNEL ON PROJECT:

Supported by funds of this grant:

- Russel D. Andrews

Personnel not directly supported by funds of this grant:

- David R. Jones
- Yeh Yuan
- Jeannine D. Williams
- Phillip H. Thorson
- Dan E. Crocker
- Daniel P. Costa
- Burney J. Le Boeuf
- Jeffrey D. Goodyear